Analysis and Design of a Random Impulse Signal Generator Suitable for Power System Identification

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Background

There has been an increase in the usage of renewable energy sources in recent years. Most of these sources are grid-tied due to their low efficiency [1], therefore, the grid offers a stable back up. The control systems in renewable sources can inject high frequency components into the grid which can affect the stability and overall performance [2].

Models of power systems over a wideband frequency spectrum have to be obtained through system identification in order to study these systems further. The models can be used for;

- power systems simulations
- spectral analysis
- filter design

Design Considerations

The aims of the project were;

- To generate a Pseudo-Random Binary Sequence (PRBS) using a micro-processor.
- To control switches using a PRBS to generate a Pseudo-Random Impulse Sequence (PRIS).
- To perturb a power system using the generated signal
- To compare the characteristics of the developed practical impulse signal to theoretical analysis and simulations

A non-parametric system identification approach was used, given that the focus was on wideband modelling. Frequency Response Analysis (FRA) was used to model a given system as it can show the response across a wideband frequency spectrum. A signal with a near flat broadband frequency response is required for system excitation. A PRBS superimposed with an impulse signal was used. The PRBS has a near flat response up to the fundamental switching frequency while the rise and fall times of the impulse current can be controlled by altering the circuit parameters.

Hardware Design

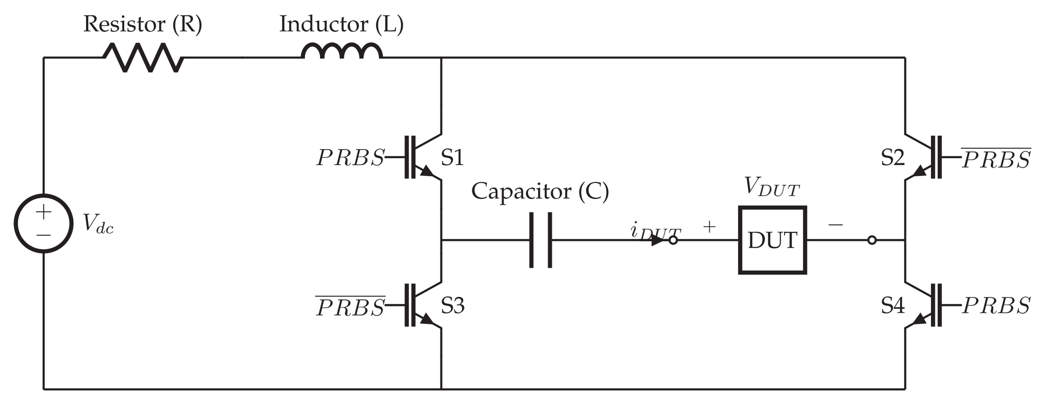

Figure 1: Main Circuit

Figure 1 shows the overview of the proposed circuit. The circuit operates by complimentary switching of an H-bridge with IGBTs as switches. In the first instance when S1 an S4 are on, the current will flow in the direction referenced by i_{DUT}. When S2 and S3 are turned on, the current will flow in the opposite direction. This results in bipolar currents. The impulses are generated by discharging **C** as the current direction can change instantaneously.

The RLC values were obtained by running a MATLAB script and are shown in Table 1. The rise time (τ_R) and fall time (τ_f) constants are also tabulated. The system is designed to have an overdamped response in order to prevent oscillations being introduced into the system.

Component	Script Value	Practical Value
Resistor	93.33 Ω	100 Ω
Inductor	62 μH	100 μH
Capacitor	2 μF	2 μF
τ_R	6.6667×10^{-7} s	1.0051×10^{-6} s
τ_f	1.8600×10^{-4} s	1.9899×10^{-4} s

Table 1: Series RLC Values

Software Development

The control algorithm for the switches was created in Arduino. A GUI was created in Python in order to pass the commands to the switches.

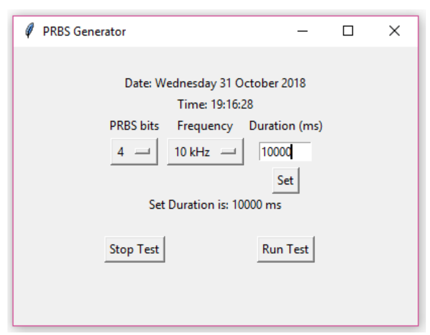

Figure 2: Python GUI

Results and Measurements

Current Waveform Characteristics

To obtain the current impulse characteristics, a short-circuit was used as the Device Under Test (DUT). The passive values in the circuit would closely match the design values. Figure 3 shows the obtained waveforms of the PRBS and PRIS. The raw scope data was imported into MATLAB and Power Spectral Densities (PSDs) were plotted as shown in Figure 3.

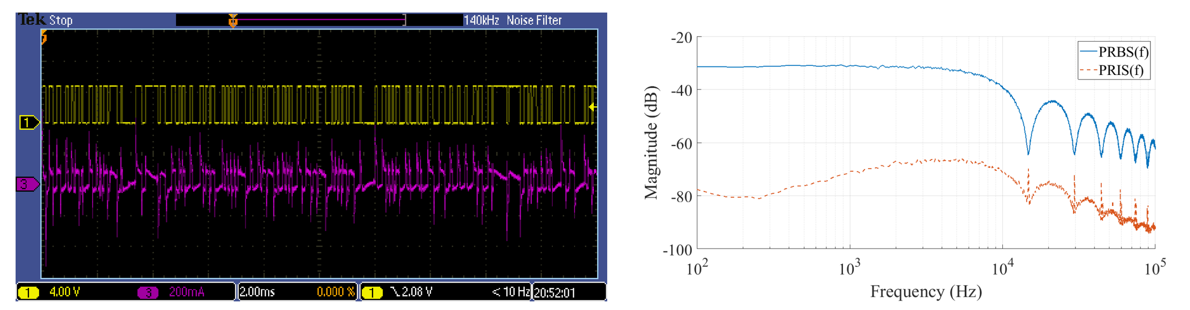

Figure 3: PRBS and PRIS (Scope and Frequency Domain)

Resistive Load identification (Off-line)

To verify the suitability of the signal for system identification, a 100Ω load was used. The impedance frequency response of an ideal resistor is flat across a wideband spectrum because its impedance is not a function of frequency, unlike inductors and capacitors. Figure 4 shows the obtained PSDs from simulations and measurements.

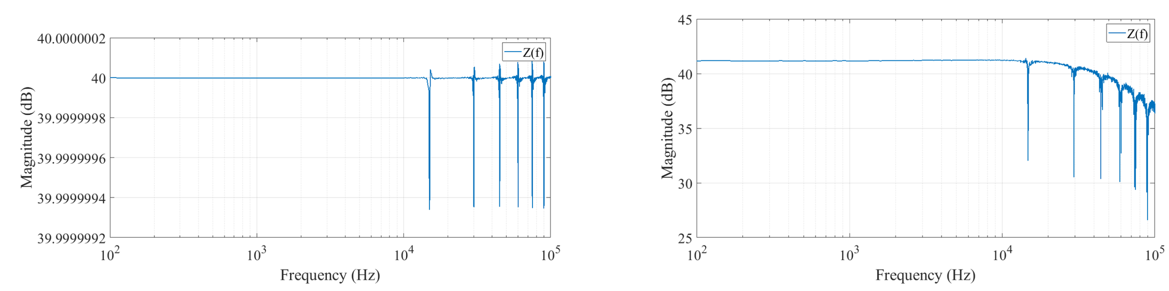

Figure 4: Simulation and Measured (100Ω Load)

The simulation shows an average impedance of 40dB across the spectrum (100Hz - 100kHz). The measured values show a near flat response with an average value of 41.2dB. The difference in results can be associated with accuracy of measuring equipment.

Rheostat perturbation (On-line)

A 100Ω rheostat load with $20V_{ac}$ source at 50Hz were connected as the DUT. A PRBS14 at 15kHz signal was injected in order to excite the system. Figure 5 shows the the measured load voltage and PRBS.

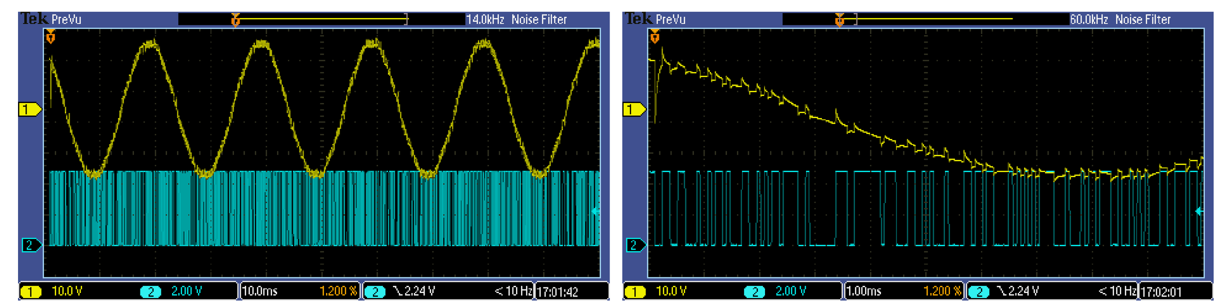

Figure 5: Perturbation of a 100Ω rheostat connected to a $20V_{ac}$ source

A fundamental 50Hz signal perturbed with a PRIS was measured at the output. Zooming into the signal, individual impulses can be seen on the 50Hz signal. The magnitude of the impulses is a function of the supply voltage of the main circuit.

The built main circuit is shown in Figure 6 and the source code can be found by following the QR code.

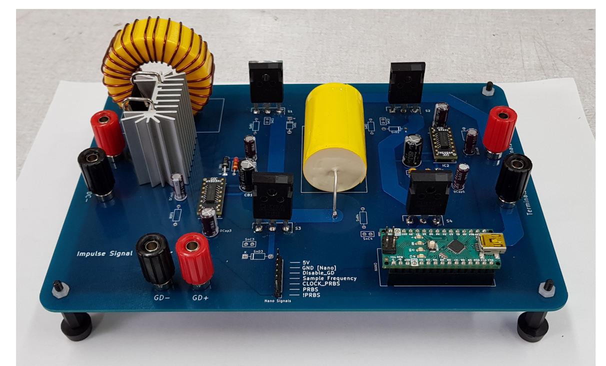

Figure 6: Main circuit built and Source Code QR

Conclusion

The generated signal shows that it can be used for system identification as shown by the resistive load off-line results. The range of flat system response is primarily a function of the fundamental switching frequency. The decaying magnitude of the PRBS affects the obtained PRIS response. Increasing the switching frequency will result in an extended range. The limitation of the measured range is due to band-limited equipment, in this case the current probe had a bandwidth of 100kHz. Using equipment with greater bandwidths will yield high fidelity results.

References

[1] S. Neshvad, S. Chatzinotas, and J. Sachau, "Online Determination of Grid Impedance Spectrum through Pseudo-Random Excitation of a Pulse Width Modulator," *Renewable Energy & Power Quality Journal*, 2014.

[2] M. Liserre, R. Teodorescu, and F. Blaabjerg, "Stability of photovoltaic and wind turbine grid-connected inverters for a large set of grid impedance values," *IEEE Transactions on Power Electronics*, vol. 21, no. 1, pp. 263–272, Jan 2006.